A Statistical Investigation of Internal Wave Propagation in the Northern South China Sea

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LONG-TERM GOALS

The long-term goal of this project is to predict the generation of internal waves over the ridges in the Luzon Strait and wave propagation across the northern South China Sea.

OBJECTIVES

The objective of this study is to provide a description of internal wave/tide propagation from the Luzon Strait to the edge of the continental shelf off China. Three issues are to be studied: 1) the relationship between the internal waves and the barotropic tides in the Luzon Strait, 2) temporal and spatial variations of internal wave properties during propagation across the deep basin of the northern South China Sea, and 3) wave transmission over the continental margin.

APPROACH

Guided by the characteristics of internal waves inferred from nonhydrostatic numerical simulation, time series analysis will be performed on real-time simulated data obtained from the Ocean Nowcast/Forecast System of Naval Research Laboratory during NLIWI. In the generation region, the study will estimate the energy conversion rate from the barotropic tides to baroclinic waves. Sources of the internal waves are to be identified. In the propagation region, waves will be traced back to the generation region to find the dependence of the amplitude of internal solitary wave on the conditions in the Luzon Strait.

WORK COMPLETED

Time series from PI's nonhydrostatic modeling study (Qian et al., 2010) have been used to establish the phase and amplitude relationship between the barotropic tides and the internal waves. Processing software for data from real-time simulation has been developed and tested. The analysis of the NRL data is to be performed in the coming year.

RESULTS

The nonhydrostatic simulation of Shaw et al. (2009) provides a description of the internal wave field generated by the barotropic tidal current over a supercritical ridge where the ridge slope is greater than

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the wave slope. The baroclinic velocity *u′* is plotted in Figure 1, in which the barotropic tidal current is zero in the top and bottom panels and to the right in the two middle panels. Distinct wave beams emit from the ridge crest and split into two nearly symmetric paths in the strongly stratified upper ocean. Wave energy propagates upward from the ridge crest along wave beams and becomes trapped in an upper-ocean wave guide by wave reflection between the surface and the lower boundary of the thermocline. Beyond $x = \pm 100$ km, mode-1 waves form and intensify into strong tidal bores. For example, a wave front of negative u' leads to a tidal bore of negative velocity at $x = -120$ km in Figure 1a. Tidal bores with positive u' form on the east side of the ridge. These tidal bores eventually develop into rank-ordered internal solitary waves (Shaw et al. 2009). Figure 1 demonstrates the complex phase propagation at generation. Over the ridge, the baroclinic velocity u' is initially negative and becomes positive following the development of the positive barotropic tidal current. Thus, a tidal bore of positive (negative) u' over the ridge top originates at the beginning of the positive (negative) barotropic tidal current.

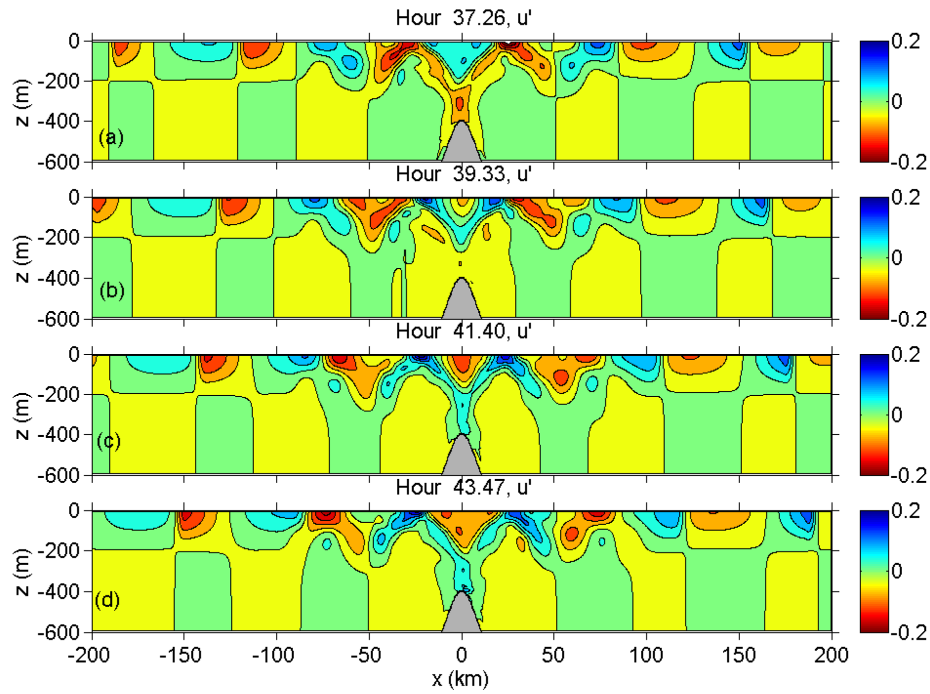

Figure 1. Development of wave beams in the contour plot of the baroclinic velocity u′ (m/s) in the experiment with ridge half-width L = 15 km and ridge height h_0 = 400 m. Time is from 37.26 hours to 43.47 hours with increments of 2 hours. The barotropic tidal flow is zero in the top and bottom panels and to the right in the two middle panels. The contour interval is 0.04 m/s.

Internal wave energy density at $z = -5$ m for the experiment shown in Figure 1 is plotted on the *x*-*t* plane in Figure 2. Locations of the first and second wave reflections from the surface appear as maxima at $x = \pm 26$ km and ± 75 km. Propagation of the mode-1 hydrostatic waves is shown as bands of energy maxima beyond $x = \pm 100$ km on each side of the ridge. The stronger ones are associated with negative (positive) *u′* on the left- (right-) hand side of the ridge in Figure 1a. The energy density of the mode-1 wave is nearly uniform. Small-scale solitary waves are shown as strings of localized maxima because the data used for plotting are stored hourly, insufficient to resolve the propagation of short waves. The speed of propagation, calculated from the slope of the position of the wave front, is slightly higher than the phase velocity of mode-1 waves. The nonhydrostatic simulation provides information on the phase relationship between the barotropic tides and the internal solitary waves.

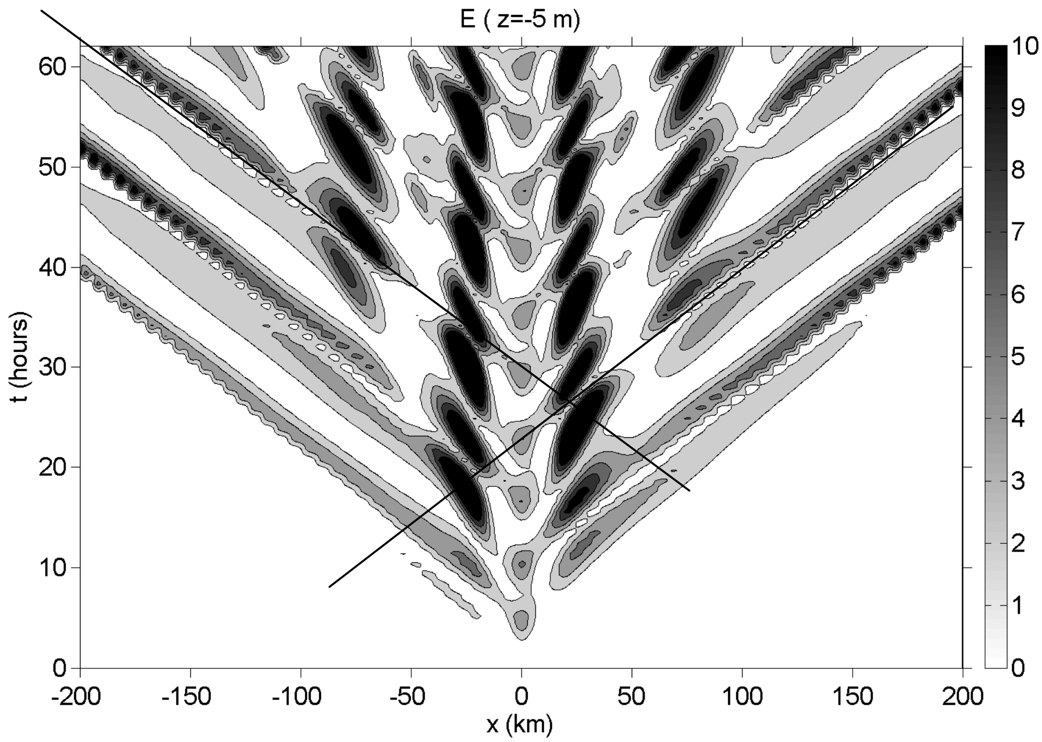

Figure 2. Contour plot of internal wave energy density (J/m^3) at z = –5 m on the x-t plane for the experiment in Figure 1. The contour interval is 2 J/m^3.

In a related project, a normalization scheme for energy flux has been developed (Qian, et al., 2010). It is found that for steep, tall ridges (such as those in the Luzon Strait) the normalized energy flux is nearly constant, independent of the ridge slope and ridge height. The study provides a practical method to estimate the energy flux of internal waves from the amplitude of the barotropic tidal current. Correlation between the observed amplitude of internal solitary waves and the barotropic tides can thus be carried out.

The results establish the correlation between internal waves and the barotropic tidal currents in both phase and amplitude. The plan is to apply these ideas to the data obtained from real-time simulation at NRL.

IMPACT/APPLICATIONS

The result will be useful to predict the generation of internal solitary waves in the northern South China Sea.

RELATED PROJECTS

This project continues the PIs effort in studying the generation and propagation of internal solitary waves in the northern South China Sea (Award Number: N00014-05-1-0280).

REFERENCES

Shaw, P.-T., D. Ko, and S.-Y. Chao (2009) Internal solitary waves induced by flow over a ridge: with applications to the northern South China Sea, J. Geophys. Res., 114, C02019, doi:10.1029/2008JC005007, 2009.

Qian, H., P.-T. Shaw, and D. S. Ko (2010) Generation of internal waves by barotropic tidal flow over a steep ridge, Deep-Sea Research I, doi:10.1016/j.dsr.2010.09.001.

PUBLICATIONS

Qian, H., P.-T. Shaw, and D. S. Ko (2010) Generation of internal waves by barotropic tidal flow over a steep ridge, Deep-Sea Research I, doi:10.1016/j.dsr.2010.09.001. [in press, refereed]